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Dissertation

# THE INFLUENCE OF SIZE AND SHAPE ON VISUAL INTENSITY DISCRIMINATION

by

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## CHAPTER I

## INTRODUCTION AND REVIEW OF THE LITERATURE

### I. INTRODUCTION

The study of visual intensity thresholds has been of interest to psychologists for many years and a large number of experiments have been performed in an attempt to isolate the variables which affect the threshold. The size of the stimulus is one of the variables which has received considerable study. Several contemporary theories exist which relate the intensity required to reach threshold to some aspect of the size of the stimulus. The present study is an attempt to test these diverse theories by determining the effects of size and shape of the stimulus on the differential threshold.

Several experiments have demonstrated that intensity thresholds decrease as the size of the stimulus is increased. Many early investigators suggested a simple functional relationship between the value of the threshold and the area of the stimulus. Later experiments have shown that these simple relationships were inadequate to explain the data. A more complex formulation of the relationship between threshold and stimulus area has been proposed by

Graham, Brown and Mote (10) and Graham and Bartlett (8,9). Lamar, Hecht, Shlaer and Hendley (17) suggest that the threshold cannot be expressed as a function of the stimulus area *per se*, but that shape and other dimensional considerations must also be taken into account. From the data of their experiment they arrived at specific equations which relate the threshold to these other dimensions of the stimulus. The present study was conducted to test the predictions deduced from the equation proposed by Lamar, Hecht, Shlaer and Hendley.

## II. REVIEW OF THE LITERATURE

Classical studies were performed, on the relation between stimulus area and absolute threshold, by Ricco (23) in 1877 and Piper (21) in 1903. Their studies have appeared frequently in textbooks as "Ricco's law" for the fovea and "Piper's law" for the periphery of the eye. The absolute threshold, having a background intensity of zero, can be considered a special case of differential threshold. Therefore, any general laws concerning the effects of area would be expected to apply to both kinds of thresholds. This has generally been found to be true and inasmuch as this study is concerned with differential thresholds, the review of the literature will be principally confined to the relevant studies involving differential thresholds.

The differential threshold is defined as the minimum difference between two lights which can be discriminated. If I is a background intensity and $\Delta I$ is the difference between a test object and the background, then the differential threshold can be expressed as $\Delta I/I$, the Weber fraction. Some investigators prefer expressing the differential threshold in terms of $\Delta I$ alone. However, for any particular value of background intensity, I, statements concerning area vs. $\Delta I$ are essentially the same as those concerning area vs. $\Delta I/I$.

A. Early studies.

Aubert (2), in 1865, was one of the earliest investigators to report on the area-intensity relationship. Using the Masson disc, he found the differential threshold to decrease as the size of the stimulus increased. Lasareff (18), using similar apparatus, found that differential threshold decreased as the visual angle was increased up to 40 minutes of arc, beyond which there was no change in the threshold. Heinz and Lippay (11) found a continuous decrease in threshold as area was increased. They suggested that the differential threshold is a function of the number of sensory elements stimulated, within certain limitations. As area is increased, more elements are stimulated and the threshold decreases.

Cobb and Moss (5) obtained thresholds of rectangular stimuli ranging from .8' to 16' of arc, at three levels of intensity. They reported near linear decreases in threshold as the visual angle increased.

B. Recent studies.

The following more recent studies are of greater significance because they report better control of the relevant variables. Steinhardt (25), obtained a large number of measurements relating $\Delta I/I$ to I. During this investigation he used circular test fields with diameters ranging from 9' to $24^{\circ}4'$ of visual angle. The data were not analyzed for the specific purpose of relating $\Delta I/I$ to area but it can be seen that $\Delta I/I$ decreases with area and that the effect is less with the larger areas.

Holway and Hurvich (14) obtained $\Delta I$ values for circular areas ranging from $1^{\circ}$ to $5^{\circ}17'$ in diameter and for levels of background intensity, I, ranging from .000625 millilamberts to 500 millilamberts. They found, as did previous investigators, an increase in visual angle results in a decrease in $\Delta I$. They reported a straight line function between log $\Delta I$ and log visual angle. Their data are thus of the form $A^{k} \cdot \Delta I = C$, where a k of .402 was found to be the slope of their straight line. The same equation, with

changes in the value of the constant, C, applies for all levels of background intensity, I. As I increases, the $\Delta I$ required to reach threshold likewise increases,(Weber's law). These two facts, the increasing of $\Delta I$ as I is increased, and the decreasing of $\Delta I$ as area is increased, were used as the basis of a physiological theory by Holway and Hurvich. They suggested the size of $\Delta I$ is correlated with the amount of excitation potentially available. This was in contrast to the theory of Heinz and Lippay which stated that the threshold is determined by the number of sensory elements being stimulated.

Crozier and Holway (6) found similar results relating $\Delta I$ to area, at different levels of I. They used rectangular stimuli which were 20.8° long and which were varied in width through .4°, .8°, 1.6°, 3.2°, 6.4° and 12.8°. Their results can be summarized by the equation, $A^{.267} \cdot \Delta I = C$, the value of C varying with the level of I. Crozier and Holway also reported further experiments to determine whether the area or the visual angle (measured as width of the stimulus) is the factor determining the value of $\Delta I$. In their experiments, the rectangles were of constant length and variable width. Under these conditions the exponential functions will be the same whether area or visual angle of

the width is used. Under conditions of a second set of rectangles of different length, they were able to determine whether area or visual angle of width was the crucial variable. Crozier and Holway concluded that the true variable is area because the log $\Delta I$ vs. log area curves agree for the two sets of rectangles.

In general, most of the above studies have reported similar results. All agree that the effect of size is to decrease the intensity required for threshold. Many of the studies can be summarized by the equation of the general form:

$$A^k \cdot \Delta I = C \tag{1}$$

These studies differ largely in their reported value of k, the simplest being Ricco's law which states that k is equal to 1 or that, $A \cdot \Delta I = C$. Equation (1), when plotted as log A vs. log $\Delta I$ is a straight line with a slope of -k and an intercept of log C.

More recently, Graham and others have suggested that a plot of log A vs. log $\Delta I$ is really a curve rather than a straight line. They claimed previous investigators had concentrated on a smooth portion of the curve and were misled in concluding the function to be a straight line. This lack of complete analysis may account for the different values of the exponent k that were obtained.

More recent studies have supported this contention. These investigations, reported in greater detail and covering a wider range of stimulus areas, have shown that a curve instead of a straight line is obtained for the log A <u>vs.</u> log $\Delta I$ function. The authors responsible for these studies are: Austin (3) using absolute thresholds; Graham and his associates (8,9,10) using absolute and differential thresholds; and Blackwell (4), Lamar et al. (17), and Hendley (12), using differential thresholds.

Blackwell (4), in a very comprehensive study, reports the contrast thresholds for circular stimuli ranging from .13' to 360' of arc on backgrounds ranging from $10^3$ to $10^{-5}$ footlamberts. A plot of log $\Delta I/I$ <u>vs.</u> log A resulted in curves which were parallel for all background intensities.

Hendley (12) obtained differential thresholds for rectangles having length-width ratios of 2/1, varying in width from 2' to 50' of visual angle. He found that $\Delta I/I$ decreased as size increased and the effect of size became less as the largest sizes were reached. The relationship between log $\Delta I/I$ and log A could best be fitted by a hyperbola instead of a straight line.

C. The experiments of Graham and his associates.

Graham and his associates (8,9,10), using both absolute and differential thresholds, proposed a series of equations to describe the area-intensity relationship. They assumed that the physiological effect of light from each elemental area of the stimulus diffuses over the surface of the retina. Therefore, the center of the retinal image of an evenly illuminated stimulus is the part which is maximally excited. They further proposed that the threshold is determined by the amount of excitation at the center of the retinal image. They concluded that the total excitation, E, at the center of the retinal image, is given by the equation:

$$E = k_1 e \int_0^{2\pi} \int_0^R \frac{r\,dr\,d\theta}{r^p} \tag{2}$$

where: $k_1$ = a constant of proportionality

$e$ = a constant intensity effect in each elemental area

$R$ = the radius of the circle

$r\,dr\,d\theta$ = an elemental area

$r$ = the distance from the center

$p$ = a constant exponent relating to a gradient effect.

From this equation it follows that the excitation, E, at the center of the retinal image is a function of the total number of elemental areas, rdrdθ, (area of the stimulus) and of the distribution of these areas around the center, (shape of the stimulus).

Graham's theory is similar to those of earlier investigators who postulated threshold to be a function of stimulus area. However, he adds a contribution by further stating that threshold is also a function of the shape of the stimulus.

All of the above experimenters have arrived at essentially similar theoretical positions. For example, when relating the effects of size on thresholds, they all agree in assuming a type of spatial summation, such that increases in the area of the stimulus result in decreases of the intensity threshold. There has been disagreement concerning the equation of the area effect, but there is general agreement that the effect is attributable to area.

D. The experiments of Lamar, Hecht, Shlaer and Hendley.

Lamar, Hecht, Shlaer and Hendley (17) conclude from their investigations that threshold is determined by the boundary of a stimulus rather than by its area. The present study follows from the results of Lamar et al. and their

experiment will be considered in detail.

Lamar et al. determined the value of $\Delta I/I$ for a series of rectangles ranging in area from .5 to 800 square minutes of visual angle, and varying in length to width ratio from 2:1 to 200:1. These data were collected at two different levels of background intensity, I, 2950 footlamberts and 17.5 footlamberts. A plot of their results in terms of log $\Delta I/I$ vs. log A produces neither a straight line nor a curve, as had been found by previous investigators, but a family of curves instead. Each curve pertains to a particular length-width ratio. This means that for any area, there were a number of different values of $\Delta I/I$ at threshold, depending upon the length-width ratio of the stimulus. This family of curves indicates that no satisfactory relationship between $\Delta I/I$ and area can be obtained if shape of the stimulus is excluded.

Lamar et al., in an attempt to unify the family of curves into one function, have reanalyzed their data along different dimensions. They have done this by employing the concept of "useful area" in place of total area. Useful area is defined as the area within a specific distance from the boundary of the test object. The useful flux required to see any object is defined as proportional to the product of the useful area and $\Delta I/I$. Since their concept of useful

flux refers to the light near the edges or boundary of the stimulus, it seems reasonable to relate the useful flux to a measure of amount of edge such as perimeter. When the data are reanalyzed in terms of log useful flux vs. the log of perimeter, they fall almost perfectly into a straight line whose slope is K. The equation for this curve is:

$$\log \text{Useful Flux} = K \log \text{Perimeter} + \log C.$$

Substituting for the value of useful flux and transforming the equation gives:

$$\Delta I/I = C \frac{P^K}{U.A.} \qquad (3)$$

where: P = perimeter

U.A. = useful area, the area within a specified distance from the edge.

The values of the constants in equation (3) which produced the best fitting curves for the data were a function of the background intensity. When the background was 17.5 footlamberts, K was 2/3, C was .13 and useful area was defined as the area within 1.5' from the edge of the stimulus. For 2950 footlamberts, K was 3/4 and useful area was defined as the area within 1' from an edge. The value for C has not been calculated.

Lamar et al. offer a physical basis of useful flux.

They suggest that a point source of light would appear on the retina as a patch of light, due to the diffraction of a 2 mm. artificial pupil. The maximum intensity of this patch would be at the center and it would diminish rapidly after 1' or slightly more than 1' of arc. Summation effects of the diffraction patterns would increase the intensity of the retinal image at the center, if the area of the point source was slowly enlarged. However, as soon as the stimulus light exceeded 2' or 3' in diameter, the summation effects due to diffraction would be very small, since this is near the limit of the diffraction circles. From this reasoning, Lamar et al. conclude that a concept of useful area between 1' and 1.5' from a boundary is consistent with contemporary optical knowledge.

## CHAPTER II

## STATEMENT OF THE PROBLEM

Lamar, Hecht, Shlaer and Hendley (17) proposed the following equation to express the relationship between the differential threshold, $\Delta I/I$, and the physical dimensions of a stimulus, for a background intensity of 17.5 foot-lamberts.

$$\Delta I/I = .13 \frac{P^{2/3}}{U.A.} \tag{3a}$$

where: P = the perimeter of the stimulus.

U.A. = useful area, the area within 1.5' from an edge of the stimulus.

In the test figures used by Lamar et al., increases in the total area of the stimuli were always accompanied by increases in the useful area. A method of testing their equation is to vary the total area without changing the useful area. According to the equation, $\Delta I/I$ should not change as a function of changes in total area.

Equation (3a) was obtained from threshold data of single test figures. If, however, perimeter and useful

area are the significant variables in the determination of the threshold, the equation should also apply to stimuli composed of more than one figure.

From the definition of useful area as the area within 1.5' from an edge, it follows that the total area of a stimulus can be varied without changing the useful area. For example, consider a 10' by 10' square as composed of two parts, a central area which is further than 1.5' from any edge, and a peripheral area (the useful area) which is within 1.5' from an edge. The central portion will be found to be a 7' by 7' square or 49 square minutes as the useful area. In contrast, a rectangle of 17' by 3' has a total area of 51 square minutes and a useful area of 51 square minutes because all of the total area is within 1.5' from an edge. Thus, these are two figures having the same useful area while differing in total area. Furthermore, it can be seen that for figures less than 3' in width, (e.g. 18' by 2', 19' by 1'), the total area will always be the same as the useful area. The perimeter and useful area of a stimulus which is composed of two identical figures will be equal to twice the perimeter and useful area of one of the figures.

A. Predictions.

The following predictions are derived from equation (3a) and from the foregoing discussion.

Prediction I. There will be an inverse relationship between the differential threshold, $\Delta I/I$, and area, for figures of less than a critical area and constant perimeter.

Prediction II. The differential threshold, $\Delta I/I$, will be constant, and independent of changes in area, for figures of more than a critical area and constant perimeter.

Prediction III. The differential threshold, $\Delta I/I$, will increase as the perimeter is increased, for figures of constant area.

Prediction IV. The differential threshold, $\Delta I/I$, can be predicted from equation (3a) for stimuli composed of two figures.

B. Method of testing Predictions I, II and III.

The first two predictions are tested by obtaining the value of $\Delta I/I$ for a series of twelve rectangles of equal perimeter (40') and varying in dimensions from 10' by 10' to 19.9' by .1'. Half of the twelve rectangles have areas of less than the critical value of 51 square minutes. These rectangles, in which area and useful area are equal, should vary in their thresholds. They are used as the test of Prediction I. The other rectangles, all with useful areas

of 51 square minutes and varying in total area, should have the same thresholds. They are used to test Prediction II. To test Prediction III, the values of $\Delta I/I$ are obtained for another series of twelve rectangles of a constant perimeter (80') and ranging in physical dimensions from 20' by 20' to 39.9' by .1'. From equation (3a) it follows that rectangles with perimeters of 80' should have higher thresholds than rectangles of equal useful area but with perimeters of 40'. A plot of the logarithm of $\Delta I/I$ *vs.* the logarithm of useful area should, therefore, result in two parallel curves, the displacement between them accountable by differences in perimeter. The second set of rectangles is also used as an additional test of Prediction I and II. This second test is valuable because it involves another critical area, 111 square minutes instead of 51 square minutes. The predicted curves for these two sets of twelve rectangles are shown in Figure I.

C. Method of testing Prediction IV.

As a test of Prediction IV, the thresholds of stimuli composed of pairs of figures were predicted from equation (3a). Slide A, a 20' by 20' square was compared with Slides B, C and D which were pairs of rectangles of 20' by 7', 20' by 5' and 20' by 3' respectively. For all four slides the thresholds are predicted to be approximately equal from calculations of

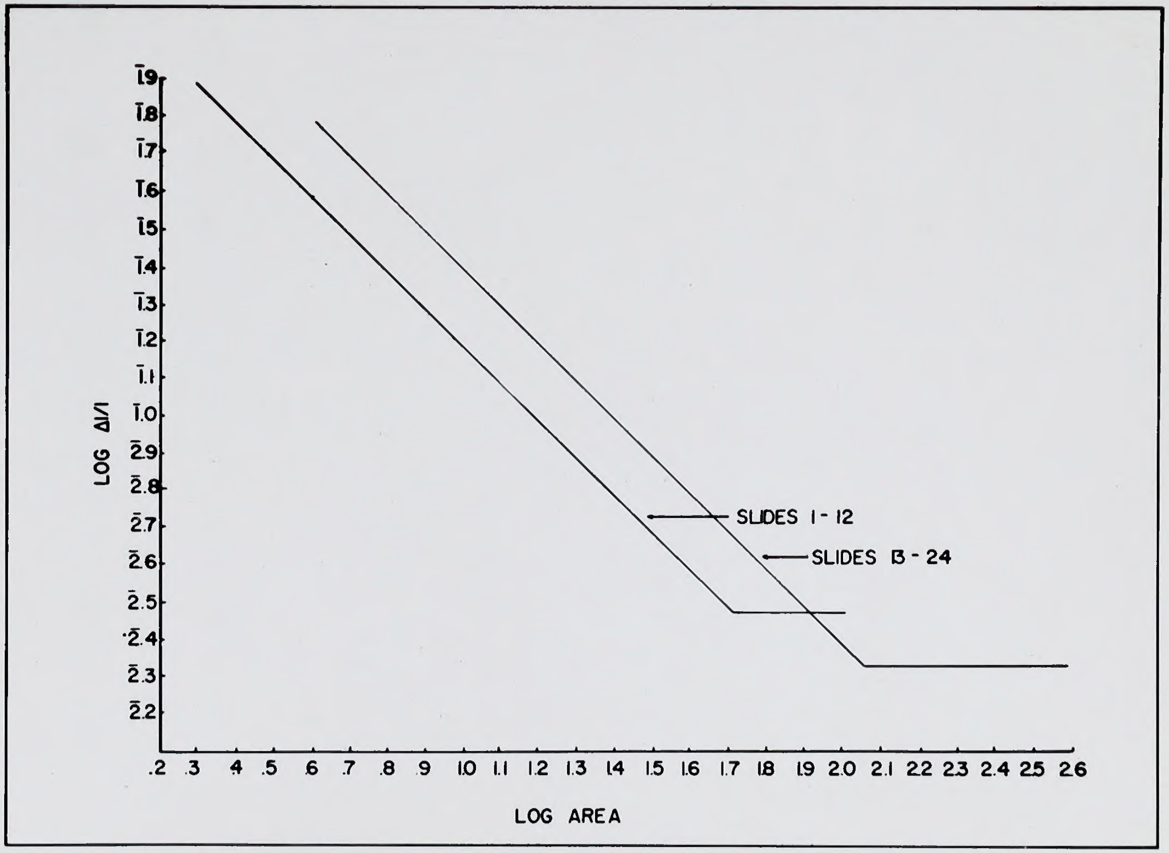


FIGURE I

CURVES PREDICTED FROM EQUATION (3a) FOR RECTANGLES 1-12 (PERIMETER = 40') AND RECTANGLES 13-24 (PERIMETER = 80')

the perimeter and useful area. As an example, each 20' by 5' rectangle of slide C has a perimeter of 50' and a useful area of 66'. Therefore, the stimulus effectively has a perimeter of 100' and a useful area of 132'. In contrast, the 20' by 20' square of slide A had a perimeter of 80' and a useful area of 111'. The difference between these slides is a difference in perimeter and useful area so that the predicted values of $\Delta I/I$ are approximately equal. Similar calculations show that all four slides should have approximately equal thresholds.

Slides A-D vary in the distance separating the pair of rectangles as well as in the sizes of the rectangles. Differences in separation, however, may be a relevant variable for the determination of the threshold. To test for this, the 20' by 5' rectangles of slide C were constructed at the different separations, slides E,F and G. The seven stimuli A-G are shown in Figure V.

D. <u>Implications of predictions for other theories.</u>

The primary purpose of the predictions was to test the equation proposed by Lamar et al. However, that equation is only from one of several contemporary theories relating the area of a stimulus to the intensity required for threshold. It is of equal importance to examine how the predictions relate to other theories. Those theories can be divided into two groups. The first of these is represented by equation (1)

as suggested by Ricco, Piper, Holway and Hurvich, Crozier and Holway and others.

$$A^k \cdot \Delta I = C \tag{1}$$

This equation states that an increase in log A results in a continuous linear decrease of log $\Delta I$. Prediction II, in contrast, asserts that beyond a critical area, log $\Delta I$ will remain constant as log A increases.

The second theory is offered by Graham and his associates in the following equation:

$$E = K_1 e \int_0^{2\pi} \int_0^R \frac{r\,dr\,d\theta}{r^P} \tag{2}$$

This equation states that the excitation at the center (and inversely the threshold) will increase as the number of unit areas increases and that it will decrease as the unit areas increase in their distance from the center. In this manner, the theory can predict that changing the shape of stimuli of constant area will alter their threshold. Both Lamar et al. and Graham and his associates state approximately the same relationship between threshold and shape; the former stresses the perimeter whereas the latter stresses the distance from the center. The two theories differ, however, in their measures of area. Lamar et al. use a critical value of area, the useful area, whereas Graham uses the total area. As a result, the precise predictions of the two theories are different.

For rectangles varying from 19.9' by .1' to 10' by 10',

decreases in threshold are predicted until widths of 3' are reached; beyond 3' the threshold is predicted to remain constant. This prediction is based on the useful area concept and cannot be made by Graham. Instead, he would predict that the threshold will continually decrease because the number of unit areas is increasing and their distance from the center is decreasing. Graham's theory might argue, however, that beyond 3' or so the change in threshold is negligible because the areas being added are far from the center and therefore contribute little. If this argument were proposed, then the differences in threshold between figures such as 15' by 5' and 35' by 5' should also be negligible because the differences are in areas beyond 3' from the center. The Lamar equation, however, predicts differences in thresholds for these and similar pairs of rectangles. The two series of rectangles can therefore be used as a test of the alternative theories of Lamar and Graham.

The equations of Lamar et al. and Graham further differ in their predictions for the thresholds of stimuli A,B,C and D. These stimuli decrease in area and increase in the separation distance between rectangles. Both of these effects should lead to an increase in threshold according to the Graham equation. Lamar et al. predicted approximately equal thresholds for these stimuli.

# CHAPTER III

# APPARATUS AND PROCEDURE

## 1. APPARATUS

A. <u>Major components</u>.

Figure II is a schematic diagram of the apparatus. The subject saw the reflection of a background screen in a piece of plate glass. An increment in intensity, $\Delta I$ was transmitted through the plate glass and appeared to be superimposed on the background. The amount of $\Delta I$ was varied by moving a light source to and from a piece of opal glass, which acted as the sedondary source. The size and shape of $\Delta I$ was varied by prepared slides which were placed in front of the opal glass.

B. <u>Details of apparatus construction</u>.

Figure III is a diagram of the details of the apparatus. The background screen was located behind this apparatus and therefore has been omitted in this side view. The background screen will be discussed later.

The observer seated comfortably at O looked monocularly through a 2 mm artificial pupil in the 4 inch conical eyepiece, C. An eyepatch was worn over the other eye and the blackened headpiece, B, shielded the subject from any external light. A blackened box, D, 14 inches by 14 inches, was attached to the headpiece. The side of

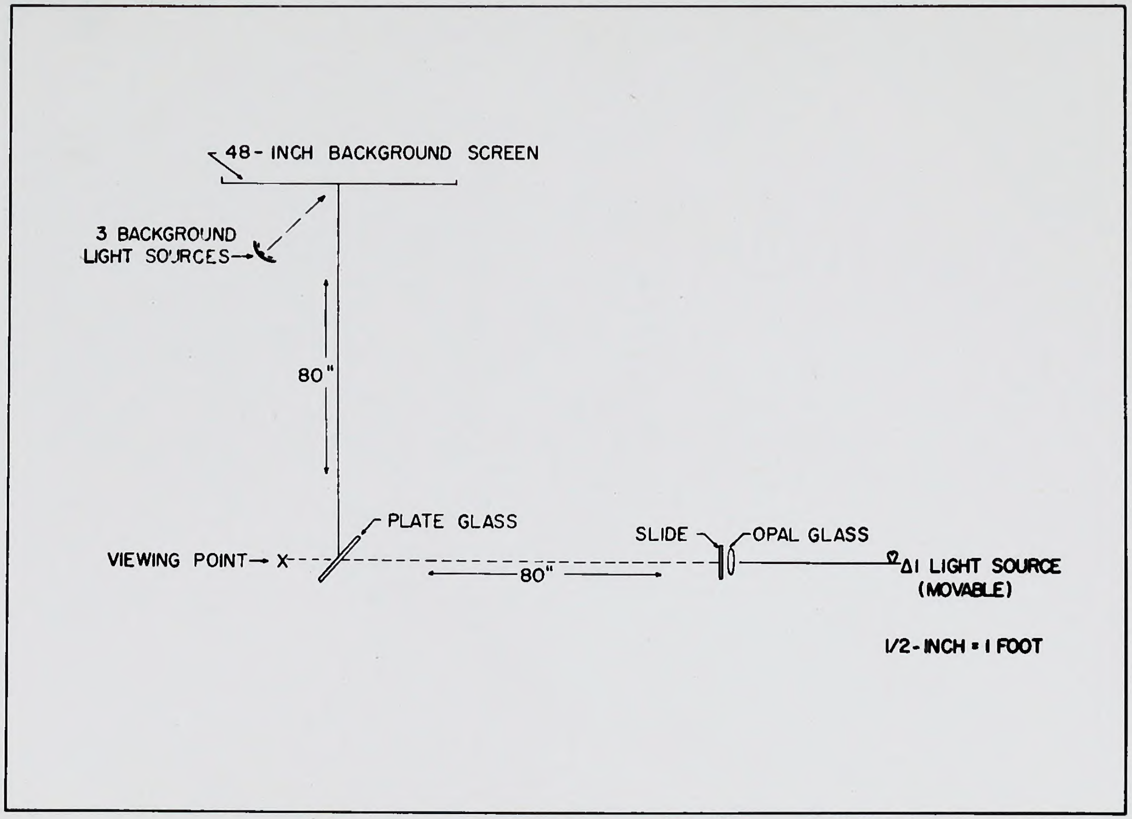


FIGURE II

SCHEMATIC DIAGRAM OF THE APPARATUS

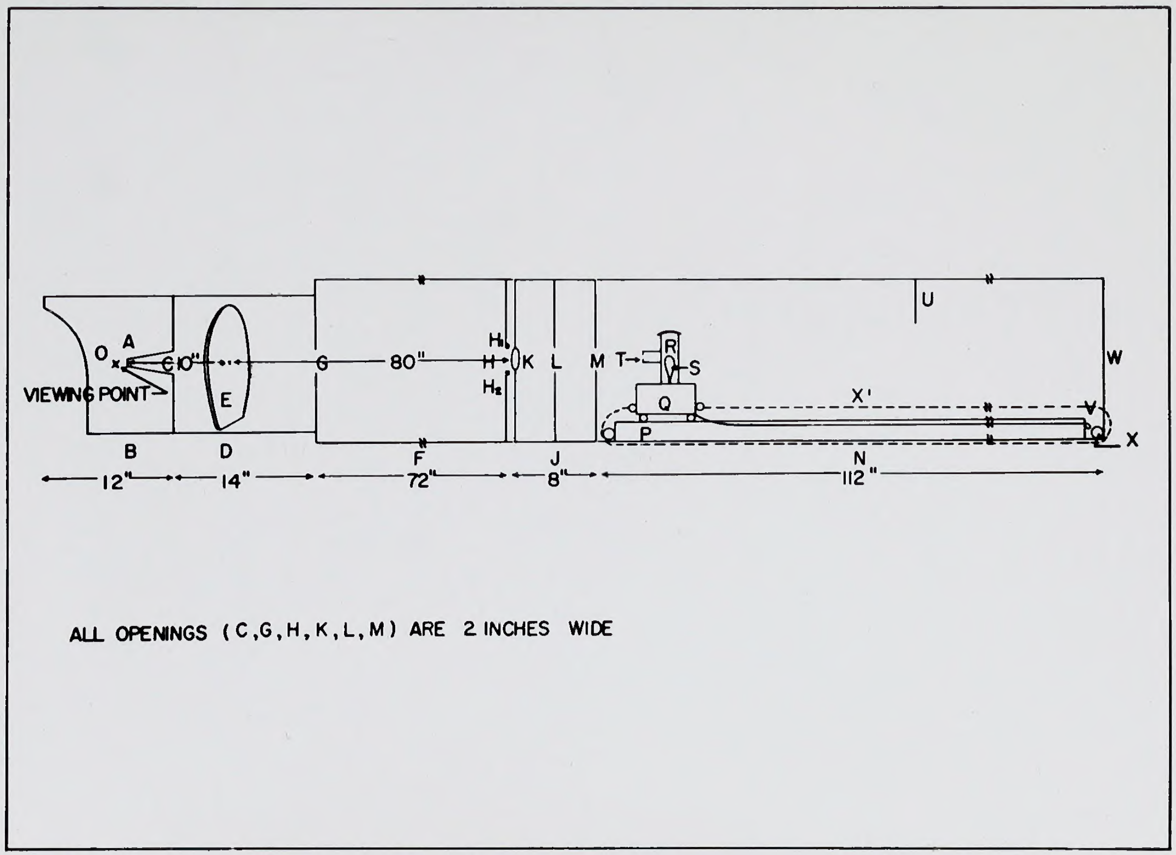


FIGURE III

DIAGRAM OF THE DETAILS OF THE APPARATUS

this box that was attached to the headpiece had a 2 inch opening into which the wide end of the eyepiece fitted. Within this box was a 12 inch diameter piece of $\frac{1}{4}$ inch plate glass, E, which was set at 45° so that it reflected the background light and transmitted the ΔI light. The side of the box to the observer's left was entirely open to permit the entrance of the background light. The center of the plate glass was 10 inches from the observer's eye. A baffle, G, with a 2 inch diameter knife-edge opening joined the box, D, to the 16 inch diameter blackened cardboard tube, F, 72 inches in length. Another 2 inch diameter baffle opeining, H, was at the far end of this tube. A slide holder, $H_1H_2$, was built around the opening, H, on the outside of the tube.

The next section of the blackened tubing, J, 8 inches in length, could be swung out of line so that the experimenter had access to the slide holder. A 2 inch diameter piece of opal glass, K, (flashed on the side nearest the observer) fitted snugly into a baffle opening adjacent to the slide holder. With this section of tubing in place, the distance between a test slide and the opal glass was approximately 3/8 of an inch. L, was a 2 inch diameter baffle opening set 4 inches from the opal glass and M, was another 2 inch diameter baffle opening set 8 inches from the opal glass and forming the far end of this section of the tube.

The last section of blackened tubing, N, was 112 inches in length, and contained a track, p, along its entire length. A dolly, Q, rested on the track and could be moved the length of the tube by means of a crank, X, and pulley system, X'. The dolly supported the $\Delta$I light housing unit, R. The light itself, S, was a GE Sound Reproducer Lamp, catalogue #7.5A/T8SC. The lamp was housed in a 5 inch metal tube of 2 inch diameter. A 2 inch arm, $1\frac{1}{4}$ inches in diameter, extended from this tube, at the height of the filament. A baffle with a 3/4 inch diameter opening, T, was placed at the end of this 2 inch arm, so that the light travelled in a relatively narrow beam the length of the 112 inch tube. A final baffle, U, was set 31 inches from the near end of the 112 inch tube, and was shaped to allow the dolly to pass through on its track. A flexible steel (spring action) tape measure, V, was attached to the dolly and indicated the position of the light as the dolly was moved within the tube. A curtain, W, covered the end of the tube. The above apparatus was used to continually vary the intensity of the $\Delta$I light stimulus at the observer's station, and to allow for changes in the size and shape of this stimulus.

C. Power supply.

The 115 volt supply was stabilized by a Thordarson

voltage regulator. The output of the regulator was fed via a variac to a step-down transformer giving an 8/9 volt supply for the $\Delta I$ lamp. The $\Delta I$ stimulus was presented for three second intervals by means of a photographic interval timer in the circuit. A Simpson voltmeter was kept in parallel in the circuit and the voltage was maintained at a steady 7.6 volts with the lamp on, an amount which was found by trial and error to provide a suitable intensity of light.

D. The background field.

The background screen was a 48 inch disc of masonite, painted flat white, and illuminated by three flood lamps. This screen was seen as a 30° field with an intensity of 17.5 footlamberts, at the observer's station. The screen was 80 inches from the center of the plate glass, and since the plate glass was 10 inches from the observer's eye, the screen was effectively 90 inches from the observer's eye, the same distance as the $\Delta I$ test stimulus. The reflections from the front and back surfaces of the $\frac{1}{4}$ inch thick plate glass were slightly displaced spatially. The effect of this displacement was to cancel any irregularities in the surface of the screen so that the screen appeared perfectly smooth and evenly illuminated from the observer's position.

Four small pieces of black tape were centered on the background screen to orient the subject. The pieces of tape were 1/8 inch squares and were placed $2\frac{1}{2}$ inches apart, (visual angle of 95') at the four corners of a diamond. The stimulus object always appeared at the center of these four orientation dots. This arrangement insured foveal vision. The subject was instructed to fixate at the center of the four dots. If he failed to fixate as directed, foveal vision was still used because the separation of the dots was approximately the diameter of the fovea.

The subject sat comfortably on a cushioned chair of adjustable height. When he was correctly centered against the conical eyepiece, he could see all the background screen and nothing else. The rest of his visual field was occupied by the dark walls of the conical eyepiece. Thus, the subject knew that his eye was in the correct position if the background screen appeared centered. This technique proved adequate and it was unnecessary to use a biting board or a head rest. Figure IV is a diagram of a test stimulus on the background screen as it appeared to the observer.

E. <u>The test stimuli</u>

1. Test slides for single-figure stimuli. Twenty-four glass slides of varying dimensions were the stimuli

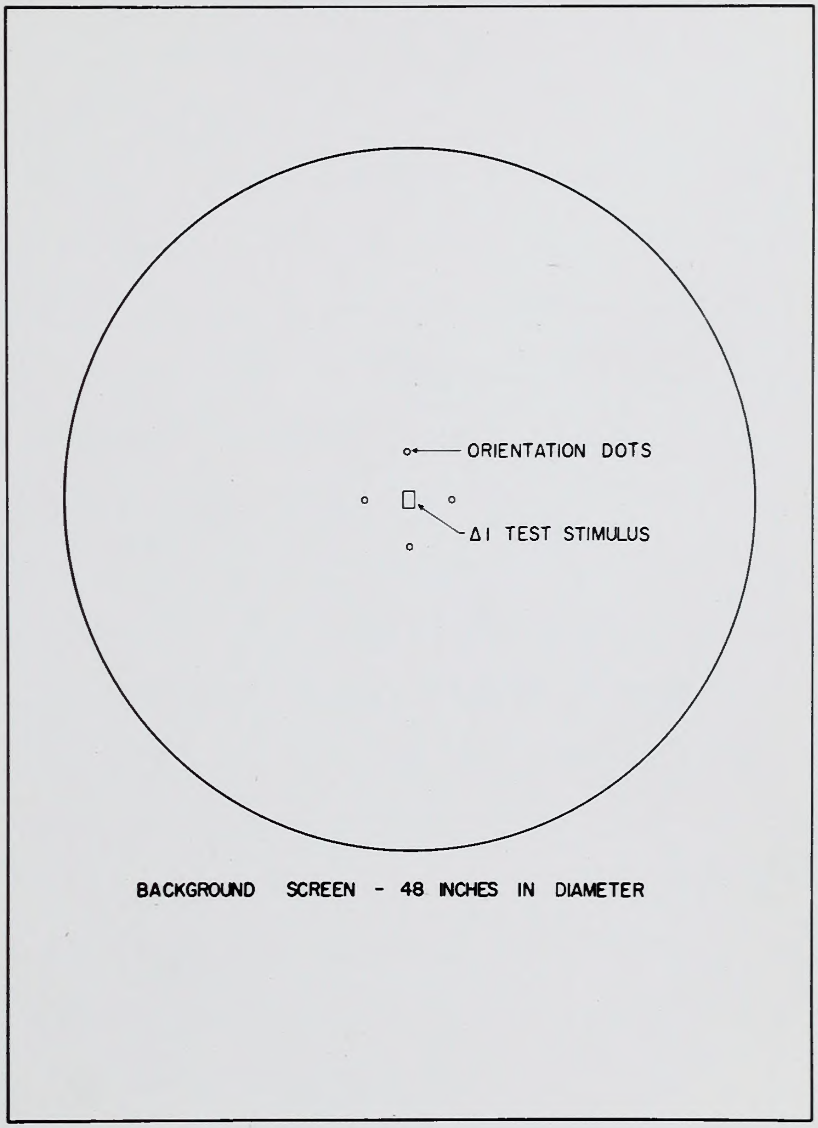


FIGURE IV

A TEST STIMULUS ON THE BACKGROUND SCREEN
AS IT APPEARED TO THE OBSERVER

used to test Predictions I, II, and III. Table I lists the dimensions of these stimuli. The slides were constructed under a microscope with a Filar Micrometer eyepiece. Double-edged Gillette razor blades were cemented in position on a $3\frac{1}{4}$ inch by 4 inch glass slide to form the rectangular stimuli. The procedure was first to place one of the blades in its appropriate position on the slide and then to set the other blade at a fixed distance and parallel to the first. Sections of a razor blade were used to form the top and bottom boundaries of the slit, thus forming a rectangle. The blades were then covered with black masking tape so that the entire slide was opaque except for the rectangle formed by the razor blade edges. The blades had sharp straight edges and were ideally suited to the preparation of these fine slits. The narrowest rectangle to be made was about 66 microns. Measurements of widths were taken along the length of this rectangle and the range of widths never exceeded 3 or 4 microns from the mean. The slit width generally varied about 5% around the mean for the narrowest rectangles. Similar measurements along the length of the rectangle were taken for all the slides. For the wider slits, the error was, of course, very much less, approaching .1% for the very wide slits. Except for the two widest slides, all were made under a microscope. The very wide

TABLE I

DIMENSIONS OF THE TEST SLIDES FOR SINGLE FIGURE STIMULI

| Slide No. | Visual Angle (minutes) | Physical Size (inches) | Perim-eter (min.) | Useful Area (sq. min) | Area (sq. min) |
|---|---|---|---|---|---|
| 1. | 10.00 x 10.00 | .2618 x .2618 | 40 | 51.00 | 100.00 |
| 2. | 13.00 x 7.0 | .3403 x .1833 | 40 | 51.00 | 91.00 |
| 3. | 14.0 x 6.0 | .3665 x .1571 | 40 | 51.00 | 84.00 |
| 4. | 15.0 x 5.0 | .3927 x .1309 | 40 | 51.00 | 75.00 |
| 5. | 16.0 x 4.0 | .4189 x .1047 | 40 | 51.00 | 64.00 |
| 6. | 17.0 x 3.0 | .4451 x .0785 | 40 | 51.00 | 51.00 |
| 7. | 17.8 x 2.2 | .4660 x .0576 | 40 | 39.16 | 39.16 |
| 8. | 18.5 x 1.5 | .4843 x .0393 | 40 | 27.75 | 27.75 |
| 9. | 19.2 x .8 | .5027 x .0209 | 40 | 15.36 | 15.36 |
| 10. | 19.6 x .4 | .5131 x .0105 | 40 | 7.84 | 7.84 |
| 11. | 19.8 x .2 | .5184 x .0052 | 40 | 3.96 | 3.96 |
| 12. | 19.9 x .1 | .5210 x .0026 | 40 | 1.99 | 1.99 |

TABLE I (continued)

DIMENSIONS OF THE TEST SLIDES FOR SINGLE FIGURE STIMULI

| Slide No. | Visual Angle (minutes) | Physical Size (inches) | Perimeter. (min.) | Useful Area (sq. min) | Area (sq. min) |
|---|---|---|---|---|---|
| 13. | 20.0 x 20.0 | .5236 x .5236 | 80 | 111.00 | 400.00 |
| 14. | 30.0 x 10.0 | .7854 x .2618 | 80 | 111.00 | 300.00 |
| 15. | 33.0 x 7.0 | .8639 x .1833 | 80 | 111.00 | 231.00 |
| 16. | 35.0 x 5.0 | .9163 x .1309 | 80 | 111.00 | 175.00 |
| 17. | 36.0 x 4.0 | .9425 x .1047 | 80 | 111.00 | 144.00 |
| 18. | 37.0 x 3.0 | .9687 x .0785 | 80 | 111.00 | 111.00 |
| 19. | 37.8 x 2.2 | .9896 x .0576 | 80 | 83.16 | 83.16 |
| 20. | 38.5 x 1.5 | 1.0079 x .0393 | 80 | 57.75 | 57.75 |
| 21. | 39.2 x .8 | 1.0263 x .0209 | 80 | 31.36 | 31.36 |
| 22. | 39.6 x .4 | 1.0367 x .0105 | 80 | 14.84 | 14.84 |
| 23. | 39.8 x .2 | 1.0420 x .0052 | 80 | 7.96 | 7.96 |
| 24. | 39.9 x .1 | 1.0446 x .0026 | 80 | 3.99 | 3.99 |

slits exceeded the visual field of the microscope and were constructed in a similar fasion using an accurate two coordinate measuring device.

2. Test slides for two-figure stimuli. The seven slides A-G, were constructed under a microscope in exactly the same way as the slides 1-24. The center strip separating the pair of rectangles was made using razor blade edges. A diagram of these slides with their dimensions is given in Figure V.

F. Photometry.

The intensity on the opal glass was varied by movements of the $\Delta$I light source along the track. The change in intensity at the opal glass as a function of the distance of the light source was measured with a photoelectric cell. The measurements were found to be similar to, though not exactly the same as, those which would be predicted from the inverse square law. These photocell readings were measures of relative light in the tube as a function of distance. A direct measure of the absolute amount of light at a few points in the tube was taken with a Macbeth Illuminometer, and the amounts of light corresponding to the other distances were calculated from the photocell information. To obtain the Macbeth readings, the conical eyepiece was removed and the Macbeth was placed in

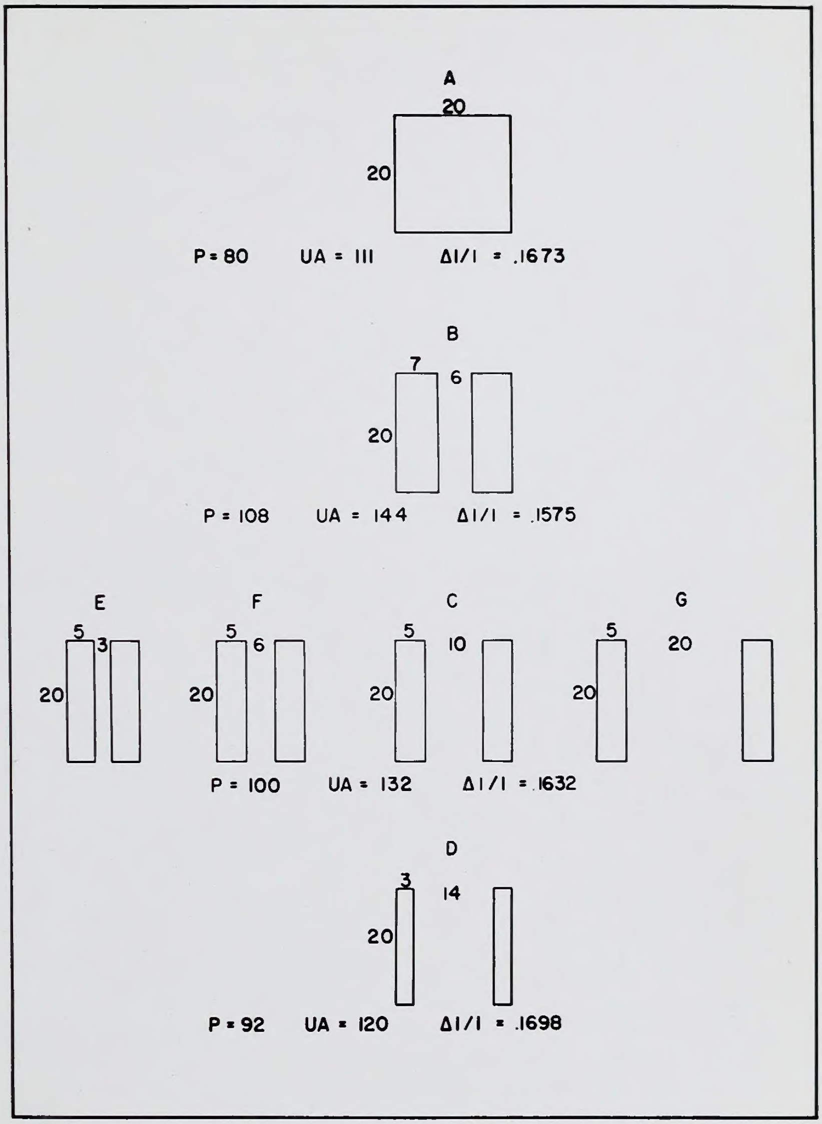


FIGURE V

TEST SLIDES A-G FOR TWO-FIGURE STIMULI. INCLUDED ARE THE DIMENSIONS OF THE FIGURES AND THEIR PREDICTED RELATIVE THRESHOLDS BASED ON THE EQUATION

$$\Delta I/I = P^{2/3}/UA$$

front of the first baffle. The 2 inch diameter opal glass and baffles that were in the 8 inch section of tubing provided too small a test field to be measured by the Macbeth. They were therefore replaced by a 7 inch diameter piece of opal glass, for measurement purposes. The Macbeth Illuminometer was also used to measure the background screen of 17.5 footlamberts.

## II. PROCEDURE

A. Experiment I.

The purpose of this experiment was to obtain the threshold values, $\Delta I/I$, for each of the twenty-four slides appearing in Table I, and to thereby test the first three predictions.

1. Method. The "up-and-down" method (7), which is essentially a modified method of limits, was used to obtain the thresholds. In the method of limits, the experimenter presents the $\Delta I$ stimulus well below the threshold and increases it slowly until the subject sees it, or else starts above the threshold and slowly decreases the $\Delta I$ stimulus until the subject no longer sees it. In the up-and-down method, the $\Delta I$ stimulus is presented at about threshold and is increased or decreased, from trial to trial, depending on whether or not the subject sees it. For example,

if the subject sees the $\Delta I$ stimulus on the first presentation, it is decreased for the second; if he sees it on the second, it is decreased for the third; if he does not see it on the third trial, it is increased for the fourth, and so on. The result is that each presentation of the $\Delta I$ stimulus is just about at the subject's threshold; if he deviates at all from his threshold, the stimuli will be more obviously present or absent and his responses will return him to his threshold region. The advantage of this particular method is that every response made is close to the threshold so that little time is wasted obtaining responses to obviously subliminal or supraliminal stimuli.

2. Subjects. A male graduate student, RDB and a female undergraduate, LB, were the subjects in the experiment. The visual acuity (Snellen) for the preferred eye of each subject was 20/20 (right eye for RDB and left eye for LB). The subjects were chosen for cooperativeness and interest in the experiment. This selection was a precaution in order to obtain reliable results because of the tedious nature of the observations. The subjects were paid $1.00 per hour. Preliminary training for another subject was started and then discontinued because his results were inconsistent and he appeared to lose interest.

3. Determination of a threshold. An experimental

session was conducted as follows: Using his preferred eye, the subject looked into the 2 mm artificial pupil and light adapted for two minutes. He was then given a verbal "ready" signal, and one second later the interval timer was pressed. This made an audible click which indicated that the $\Delta I$ light had been turned on; after three seconds, another audible click indicated that the light was off and the subject responded "yes" or "no" depending on whether or not he saw the stimulus. During a seven-second interval between stimuli, the experimenter recorded the response and turned the crank which moved the $\Delta I$ light to its new position. The $\Delta I$ light was always changed by equal increments of .04 log intensity units.

A series of sixty-five or more responses was obtained for each slide. The first five responses were considered a warm-up period and were discounted. Fifty of the responses were made to the test stimuli and constituted the threshold data which was analyzed in the results. The remaining responses (usually ten) were control trials in which no stimulus was presented. These trials were randomly interspersed among the true stimuli to discourage guessing and suggestion effects. To present a control trial, the plug between the transformer and the $\Delta I$ light was silently disconnected.

Everything else was exactly the same and the subjects had no knowledge of whether the trial was a true trial or a control. The subjects were informed during the preliminary training period that occasionally no stimulus would be presented. During this training, the subjects learned to minimize the number of times they responded "yes" to a control trial and they remained relatively consistent in the percentage of times they would do so. RDB had an average of one and a half per cent "yes" responses to control trials, with a range from zero per cent to five per cent during any one day. LB averaged about six per cent "yes" responses, with a range from two per cent to twelve per cent. On three occasions, one for RDB, and two for LB, the threshold data was discounted because the subject reported an excessively high percentage of "yes" responses to control trials. RDB gave three "yes" responses out of fourteen control trials to the second slide during one day. Since this was above his usual error (he never gave more than one "yes" during any one slide), the day's trials were discontinued and repeated the next day. On one day, LB averaged twenty one per cent (twenty-one out of ninety-nine) "yes" responses to control stimuli. The data for the entire day was discounted and repeated the next day. On another occasion, LB gave four "yes" responses out of fourteen control trials for one slide. The

Everything else was exactly the same and the subjects had no knowledge of whether the trial was a true trial or a control. The subjects were informed during the preliminary training period that occasionally no stimulus would be presented. During this training, the subjects learned to minimize the number of times they responded "yes" to a control trial and they remained relatively consistent in the percentage of times they would do so. RHB had an average of one and a half per cent "yes" responses to control trials, with a range from zero per cent to five per cent during any one day. LB averaged about six per cent "yes" responses, with a range from two per cent to twelve per cent. On three occasions, one for RHB, and two for LB, the threshold data was discounted because the subject reported an excessively high percentage of "yes" responses to control trials. RHB gave three "yes" responses out of fourteen control trials to the second slide during one day. Since this was above his usual error (he never gave more than one "yes" during any one slide), the day's trials were discontinued and repeated the next day. On one day, LB averaged twenty one per cent (twenty-one out of ninety-nine) "yes" responses to control stimuli. The data for the entire day was discounted and repeated the next day. On another occasion, LB gave four "yes" responses out of fourteen control trials for one slide. The

data for that slide was also discounted and the slide was immediately redone.

4. Preliminary training. Each subject was given about ten to fifteen hours of preliminary training. The training involved familiarizing the subjects with the experimental apparatus and procedure. During this training, an approximate threshold was obtained for each of the twenty-four slides. This approximation was used as the initial presentation point in the up-and-down method of the experiment proper. It was hoped that during the preliminary training the subjects would become well acquainted with their tasks so that further practice effects would be at a minimum during the course of the experimental trials.

5. Daily sessions. A series of sixty-five responses for a slide was obtained in approximately eleven minutes, and rest periods of ten to fifteen minutes were taken between slides. The determination of six thresholds a day took about two to three hours. Generally, a two to three hour session was held daily; on two occasions two such sessions were held in a day, one in the early afternoon and one in the evening. The subjects reported no fatigue during the experimental trials. Since the threshold for six slides was obtained in one day, a threshold for each of the twenty-four slides was obtained in a four day period. The order of

presentation of the slides was counterbalanced in order to avoid any systematic bias of the data due to fatigue or practice effects. The order of presentation of the twenty-four slides was:

| | | | |
|---|---|---|---|
| Session | 1 | slide | 1, 21, 17, 5, 9, 13. |
| | 2 | | 24, 4, 8, 20, 16, 12. |
| | 3 | | 22, 2, 6, 18, 14, 10. |
| | 4 | | 3, 23, 19, 7, 11, 15. |

The entire procedure was then repeated so that another threshold based on fifty responses was obtained for each of the twenty-four slides. Thus, the final $\Delta I/I$ values were based on one hundred responses for each slide. The order of presentation of the slides was reversed for the second four sessions; the fifth session began with slide 15, 11, etc., the sixth session began with slide 10 and so on.

A mean and a standard deviation for each group of fifty responses was obtained for each of the twenty-four slides. The two means of each slide were then compared in terms of the average of the two standard deviations. When it was found that any two means differed from each other by more than two sigmas, the threshold for that slide was obtained for a third time. It was felt that when such a difference occurred it was because one of the means reflected

error due to fatigue, eyestrain, change in subject's criterion of seeing, or any other of a number of reasons. It was therefore decided to discard that threshold measure which deviated the most from the other two. This procedure applied to only three of the slides of RDB and four of the slides of LB. It is worthwhile to note that the three slides which were deviants for subject RDB had been presented immediately following each other during one afternoon session. All three were found to have thresholds far below measures of the same slides on the two other occasions. It seems likely, therefore, that there was a temporary shift in threshold for one of the above mentioned reasons and that the best thing to do was to discard the data.

B. Experiment II

The purpose of this experiment was to obtain the threshold values $\Delta I/I$ for each of the seven slides, A-G, (Figure V) and to thereby test Prediction IV.

The subject used was RDB and the procedure and method were almost identical to that used in Experiment I. A change was made in the number of responses obtained. For a given slide, thirty-five responses were obtained; the first five were discounted, five were control trials of no stimulus, (in the total of one hundred seventy-five control trials, the subject never responded "yes"), and the remaining

twenty-five were used to compute a single threshold value. A threshold was obtained in approximately six minutes and the seven slides, in random order, were measured in a one to one-and-a-half hour session. This procedure was repeated five times during a three day period, so that five threshold values for each slide could be compared. Experiment II was conducted about two months after Experiment I.

## CHAPTER IV

## RESULTS

A. Experiment I.

1. Threshold computations. Each series of fifty responses per slide was grouped into a frequency distribution. The mean of that distribution was taken as the differential threshold, $\Delta I/I$. Tables II and IIA contain the thresholds of each slide for each series of fifty responses. A graph of the log $\Delta I/I$ values of each slide for each series is given in Figures VI (subject RDB) and VIA (subject LB) for slides 1-12 and VII (subject RDB) and VIIA (subject LB) for slides 13-24. In all four of these Figures, the values of $\Delta I/I$ predicted from equation (3a) are included for comparison. For the slides with perimeters of 40', the logarithm of equation (3a) is:

$$\log \Delta I/I = .1820 - \log U.A. \tag{4}$$

For slides with perimeters of 80', it is:

$$\log \Delta I/I = .3826 - \log U.A. \tag{5}$$

2. Reliability of the thresholds. The purpose of obtaining the threshold measures twice was to check the consistency of the subjects and to increase the stability of

TABLE II

DIFFERENTIAL THRESHOLDS (LOG $\Delta I/I$) OF SLIDES 1-24, BASED ON EACH SERIES OF FIFTY RESPONSES SUBJECT RDB

| Slide number | First series Log $\Delta I/I$ | Second series Log $\Delta I/I$ | Slide number | First series Log $\Delta I/I$ | Second series Log $\Delta I/I$ |
|---|---|---|---|---|---|
| 1. | $\bar{2}.3913$ | $\bar{2}.4889$ | 13. | $\bar{2}.3289$ | $\bar{2}.3097$ |
| 2. | $\bar{2}.4777$ | $\bar{2}.4089$ | 14. | $\bar{2}.3769$ | $\bar{2}.3001$ |
| 3. | $\bar{2}.4169$ | $\bar{2}.3817$ | 15. | $\bar{2}.2985$ | $\bar{2}.2697$ |
| 4. | $\bar{2}.4009$ | $\bar{2}.4505$ | 16. | $\bar{2}.3001$ | $\bar{2}.2393$ |
| 5. | $\bar{2}.4841$ | $\bar{2}.4489$ | 17. | $\bar{2}.3385$ | $\bar{2}.3721$ |
| 6. | $\bar{2}.4921$ | $\bar{2}.4969$ | 18. | $\bar{2}.3865$ | $\bar{2}.3417$ |
| 7. | $\bar{2}.6009$ | $\bar{2}.6073$ | 19. | $\bar{2}.4777$ | $\bar{2}.4137$ |
| 8. | $\bar{2}.7625$ | $\bar{2}.7385$ | 20. | $\bar{2}.6281$ | $\bar{2}.5961$ |
| 9. | $\bar{2}.9881$ | $\bar{2}.9337$ | 21. | $\bar{2}.8745$ | $\bar{2}.8729$ |
| 10. | $\bar{1}.2697$ | $\bar{1}.1961$ | 22. | $\bar{1}.2089$ | $\bar{1}.1721$ |
| 11. | $\bar{1}.4969$ | $\bar{1}.5561$ | 23. | $\bar{1}.3865$ | $\bar{1}.4713$ |
| 12. | $\bar{1}.8969$ | $\bar{1}.8873$ | 24. | $\bar{1}.7529$ | $\bar{1}.7257$ |

TABLE IIA

DIFFERENTIAL THRESHOLDS (LOG $\Delta I/I$) OF SLIDES 1-24, BASED ON EACH SERIES OF FIFTY RESPONSES SUBJECT LB

| Slide number | First series Log $\Delta I/I$ | Second series Log $\Delta I/I$ | Slide number | First series Log $\Delta I/I$ | Second series Log $\Delta I/I$ |
|---|---|---|---|---|---|
| 1. | $\bar{2}.4281$ | $\bar{2}.4521$ | 13. | $\bar{2}.2985$ | $\bar{2}.3257$ |
| 2. | $\bar{2}.3369$ | $\bar{2}.3193$ | 14. | $\bar{2}.2745$ | $\bar{2}.3225$ |
| 3. | $\bar{2}.3337$ | $\bar{2}.3785$ | 15. | $\bar{2}.1801$ | $\bar{2}.3033$ |
| 4. | $\bar{2}.3593$ | $\bar{2}.4457$ | 16. | $\bar{2}.2185$ | $\bar{2}.2521$ |
| 5. | $\bar{2}.3849$ | $\bar{2}.4025$ | 17. | $\bar{2}.2713$ | $\bar{2}.3241$ |
| 6. | $\bar{2}.4009$ | $\bar{2}.3161$ | 18. | $\bar{2}.3033$ | $\bar{2}.2905$ |
| 7. | $\bar{2}.4521$ | $\bar{2}.4505$ | 19. | $\bar{2}.3881$ | $\bar{2}.4185$ |
| 8. | $\bar{2}.5913$ | $\bar{2}.6729$ | 20. | $\bar{2}.5433$ | $\bar{2}.5801$ |
| 9. | $\bar{2}.8905$ | $\bar{1}.0185$ | 21. | $\bar{2}.7753$ | $\bar{2}.8345$ |
| 10. | $\bar{1}.1177$ | $\bar{1}.0905$ | 22. | $\bar{1}.0681$ | $\bar{1}.0985$ |
| 11. | $\bar{1}.3081$ | $\bar{1}.3001$ | 23. | $\bar{1}.2857$ | $\bar{1}.3993$ |
| 12. | $\bar{1}.9129$ | $\bar{1}.8073$ | 24. | $\bar{1}.9193$ | $\bar{1}.8409$ |

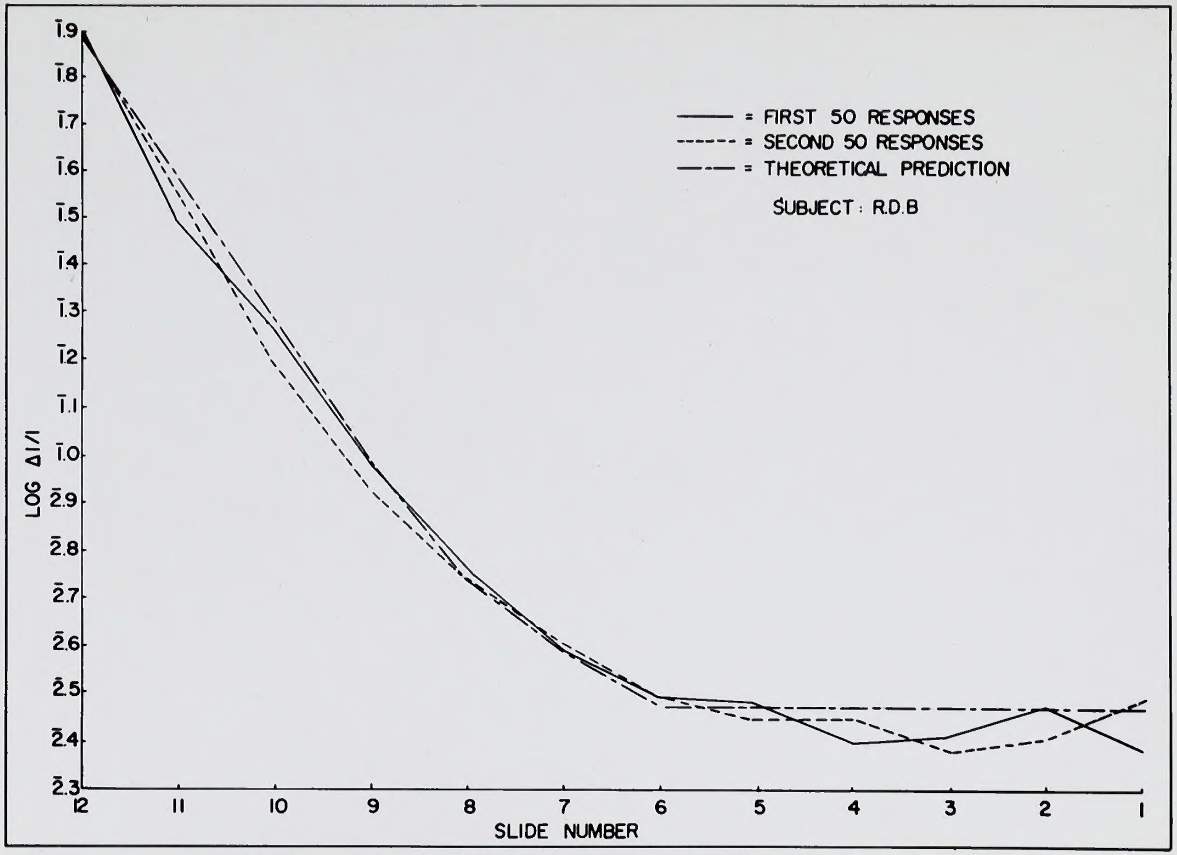


FIGURE VI

DIFFERENTIAL THRESHOLDS (LOG $\Delta$I/I) OF SLIDES 1-12, BASED ON EACH SERIES OF FIFTY RESPONSES. THE PREDICTED THRESHOLD VALUE OF EACH SLIDE IS ALSO GIVEN.
SUBJECT RDB

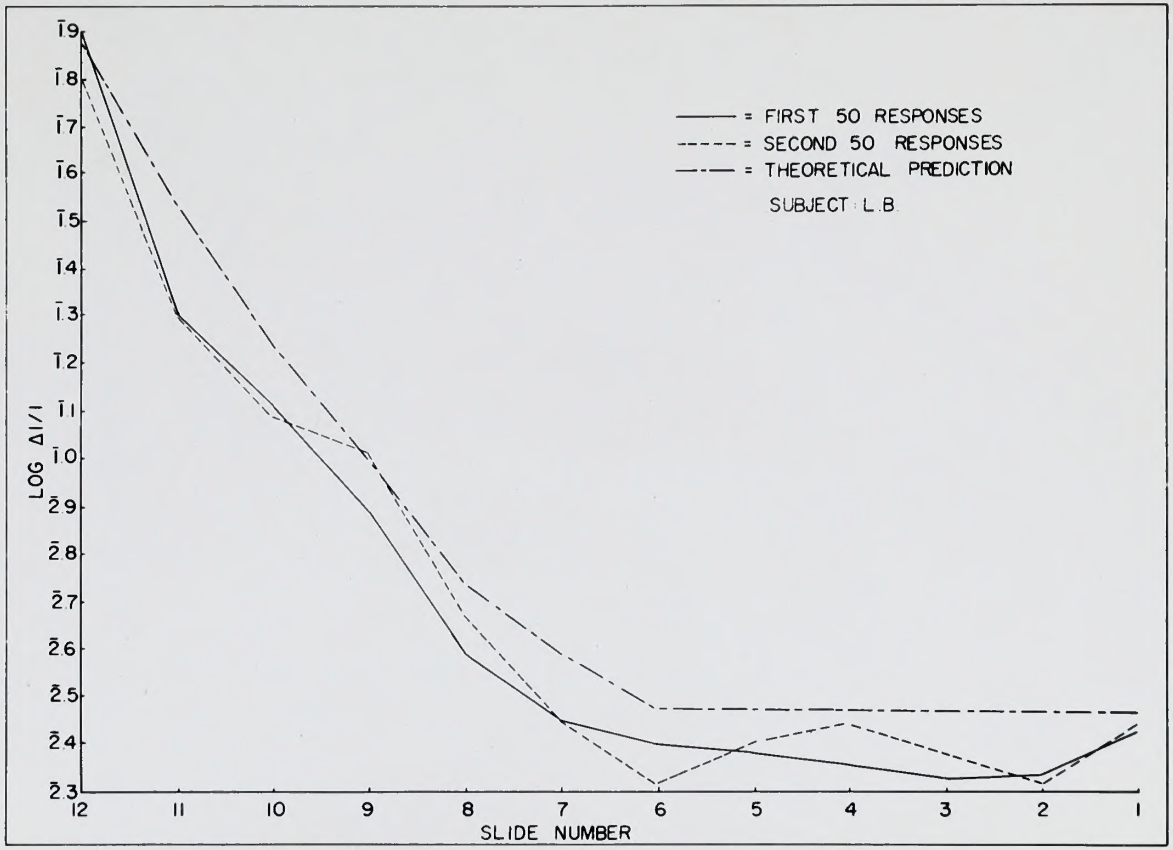


FIGURE VIA

DIFFERENTIAL THRESHOLDS (LOG $\Delta$I/I) OF SLIDES 1-12, BASED ON EACH SERIES OF FIFTY RESPONSES. THE PREDICTED THRESHOLD VALUE OF EACH SLIDE IS ALSO GIVEN
SUBJECT LB

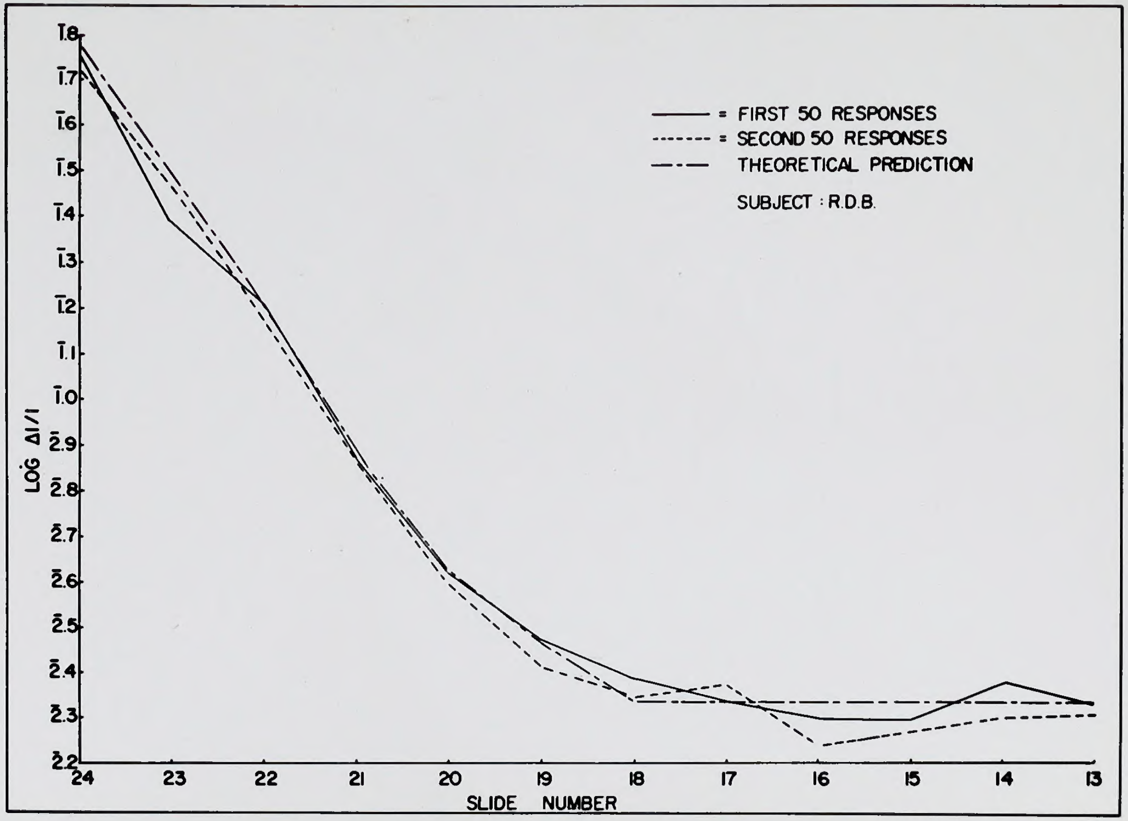


FIGURE VII

DIFFERENTIAL THRESHOLDS (LOG $\Delta$I/I) OF SLIDES 13-24 BASED ON EACH SERIES OF FIFTY RESPONSES. THE PREDICTED THRESHOLD VALUE OF EACH SLIDE IS ALSO GIVEN
SUBJECT RDB

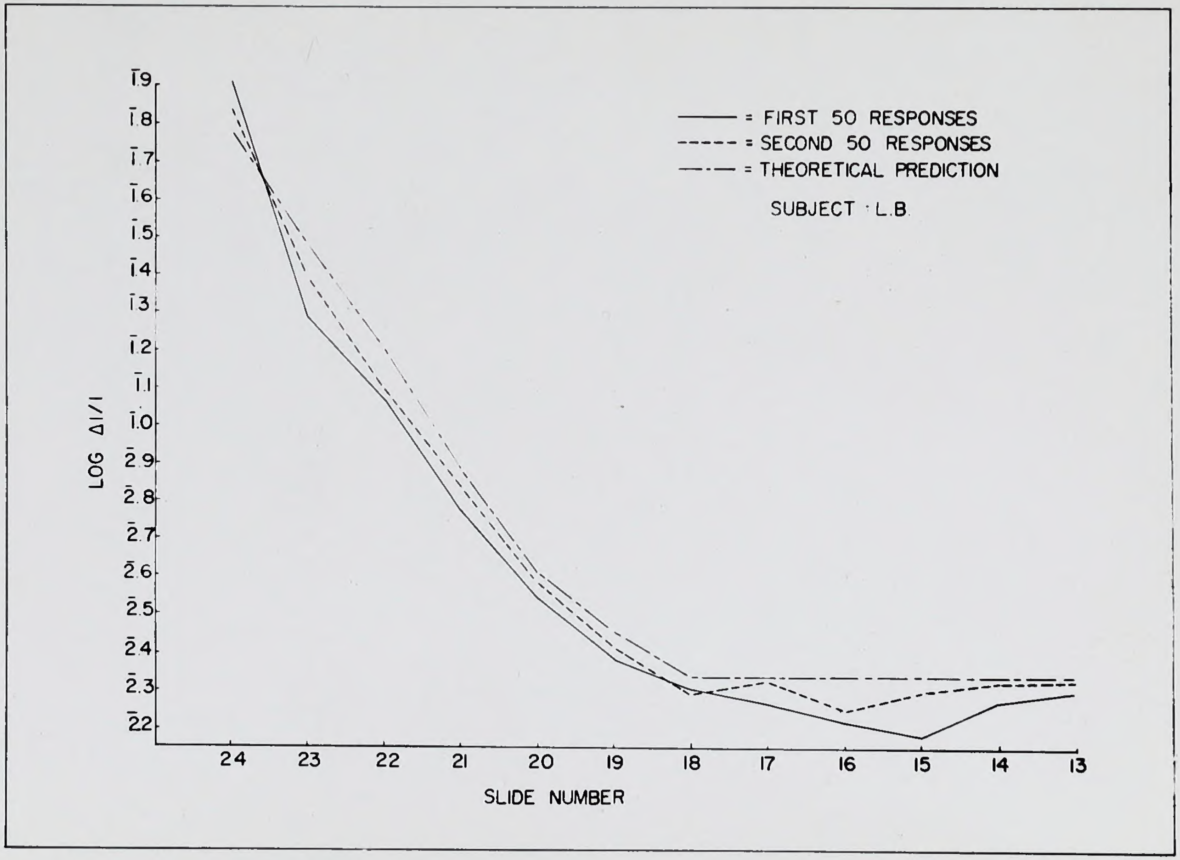


FIGURE VIIA

DIFFERENTIAL THRESHOLDS (LOG $\Delta I/I$) OF SLIDES 13-24 BASED ON EACH SERIES OF FIFTY RESPONSES. THE PREDICTED THRESHOLD VALUE OF EACH SLIDE IS ALSO GIVEN
SUBJECT LB

the measures. The curves of the two sets of threshold measures in Figures VI, VIA, VII and VIIA correspond well, indicating high consistency. Occasionally, repeated measures on the same slide differ, but the differences from slide to slide are so much greater that the differences due to repeated measurements may be discounted.

A simple comparison of differences between slides with differences due to repeated measurement was obtained in the form of rank-order correlations. Prediction I stated that slides 6-12 and 18-24 should continually increase in values of log $\Delta I/I$. Rank-order correlations of the first and second set of threshold measures for these slides were found to be 1.00 in all cases as predicted. Prediction II stated that slides 1-6 and 13-18 should be equal in their values of log $\Delta I/I$. If they are equal, then there should be no systematic differences and rank-order correlations for repeated measures should be zero. As predicted, none of the rank-order correlations for these slides was found to be significantly different from zero. Table III contains the rank-order correlations for both subjects.

3. Trend Analysis of the data. The first and second series of threshold measurements were combined to form the final differential thresholds based on the total of one hundred responses for each slide. These log $\Delta I/I$ values are

TABLE III

RANK-ORDER CORRELATIONS BETWEEN FIRST AND SECOND SERIES OF THRESHOLD MEASUREMENTS FOR SLIDES 1-6, 13-18, 7-12 and 19-24

| Slides correlated | Subject RDB r | Subject RDB p | Subject LB r | Subject LB p |
|---|---|---|---|---|
| 1-6 | .086 | >.1 | .314 | >.1 |
| 13-18 | .657 | >.1 | .257 | >.1 |
| 7-12 | 1.00 | <.01 | 1.00 | <.01 |
| 19-24 | 1.00 | <.01 | 1.00 | <.01 |

presented in Tables IV and IVA, along with the values predicted from equations (4) and (5).

A Lindquist trend analysis (19) was performed to determine whether or not the data fit the predicted equations (4) and (5). The analysis consisted of two tests; 1) a test for departure from pattern or shape of the predictions; and 2) a test for the vertical displacement of the predictions. Table V contains a summary of the analysis of variance results. The F tests indicate that equations (4) and (5) predict the shape of the curves for both subjects. However, the equations and the data are significantly different in vertical displacement. For subject LB the differences are very significant whereas for subject RDB they are of doubtful significance. Differences in vertical displacement are a function of the value of the constant, c, in equation (3a) of Lamar et al. The graphs of the predicted values and the empirical data appear in Figures VIII (subject RDB) and VIIIA (subject LB).

B. Experiment II

The thresholds of the seven figures of Experiment II were obtained in the same way as those of Experiment I.

1. Effect of the size of a pair of rectangles. Five threshold values, each based on twenty-five responses, were

TABLE IV

DIFFERENTIAL THRESHOLDS (LOG $\Delta I/I$) OF SLIDES 1-24, BASED ON ONE HUNDRED RESPONSES AND LOG $\Delta I/I$ VALUES PREDICTED FROM EQUATION (3a)
SUBJECT RDB

| Slide number | Log $\Delta I/I$ | Predicted Log $\Delta I/I$ | Slide number | Log $\Delta I/I$ | Predicted Log $\Delta I/I$ |
|---|---|---|---|---|---|
| 1. | $\bar{2}.4401$ | $\bar{2}.4744$ | 13. | $\bar{2}.3193$ | $\bar{2}.3373$ |
| 2. | $\bar{2}.4433$ | $\bar{2}.4744$ | 14. | $\bar{2}.3385$ | $\bar{2}.3373$ |
| 3. | $\bar{2}.3993$ | $\bar{2}.4744$ | 15. | $\bar{2}.2841$ | $\bar{2}.3373$ |
| 4. | $\bar{2}.4257$ | $\bar{2}.4744$ | 16. | $\bar{2}.2697$ | $\bar{2}.3373$ |
| 5. | $\bar{2}.4665$ | $\bar{2}.4744$ | 17. | $\bar{2}.3553$ | $\bar{2}.3373$ |
| 6. | $\bar{2}.4945$ | $\bar{2}.4744$ | 18. | $\bar{2}.3641$ | $\bar{2}.3373$ |
| 7. | $\bar{2}.6041$ | $\bar{2}.5891$ | 19. | $\bar{2}.4465$ | $\bar{2}.4627$ |
| 8. | $\bar{2}.7505$ | $\bar{2}.7387$ | 20. | $\bar{2}.6121$ | $\bar{2}.6210$ |
| 9. | $\bar{2}.9609$ | $\bar{2}.9956$ | 21. | $\bar{2}.8737$ | $\bar{2}.8842$ |
| 10. | $\bar{1}.2329$ | $\bar{1}.2877$ | 22. | $\bar{1}.1905$ | $\bar{1}.2112$ |
| 11. | $\bar{1}.5265$ | $\bar{1}.5843$ | 23. | $\bar{1}.4289$ | $\bar{1}.4817$ |
| 12. | $\bar{1}.8921$ | $\bar{1}.8831$ | 24. | $\bar{1}.7393$ | $\bar{1}.7816$ |

TABLE IVA

DIFFERENTIAL THRESHOLDS (LOG $\Delta I/I$) OF SLIDES 1-24, BASED ON ONE HUNDRED RESPONSES AND LOG $\Delta I/I$ VALUES PREDICTED FROM EQUATION (3a)
SUBJECT LB

| Slide number | Log $\Delta I/I$ | Predicted Log $\Delta I/I$ | Slide number | Log $\Delta I/I$ | Predicted Log $\Delta I/I$ |
|---|---|---|---|---|---|
| 1. | $\bar{2}.4401$ | $\bar{2}.4744$ | 13. | $\bar{2}.3121$ | $\bar{2}.3373$ |
| 2. | $\bar{2}.3281$ | $\bar{2}.4744$ | 14. | $\bar{2}.2985$ | $\bar{2}.3373$ |
| 3. | $\bar{2}.3561$ | $\bar{2}.4744$ | 15. | $\bar{2}.2417$ | $\bar{2}.3373$ |
| 4. | $\bar{2}.4025$ | $\bar{2}.4744$ | 16. | $\bar{2}.2353$ | $\bar{2}.3373$ |
| 5. | $\bar{2}.3937$ | $\bar{2}.4744$ | 17. | $\bar{2}.2977$ | $\bar{2}.3373$ |
| 6. | $\bar{2}.3585$ | $\bar{2}.4744$ | 18. | $\bar{2}.2969$ | $\bar{2}.3373$ |
| 7. | $\bar{2}.4513$ | $\bar{2}.5891$ | 19. | $\bar{2}.4033$ | $\bar{2}.4627$ |
| 8. | $\bar{2}.6321$ | $\bar{2}.7387$ | 20. | $\bar{2}.5617$ | $\bar{2}.6210$ |
| 9. | $\bar{2}.9545$ | $\bar{2}.9956$ | 21. | $\bar{2}.8049$ | $\bar{2}.8842$ |
| 10. | $\bar{1}.1041$ | $\bar{1}.2877$ | 22. | $\bar{1}.0833$ | $\bar{1}.2112$ |
| 11. | $\bar{1}.3041$ | $\bar{1}.5843$ | 23. | $\bar{1}.3425$ | $\bar{1}.4817$ |
| 12. | $\bar{1}.8601$ | $\bar{1}.8831$ | 24. | $\bar{1}.8801$ | $\bar{1}.7816$ |

TABLE V

SUMMARY OF F-TESTS FOR TREND ANALYSIS OF THE DIFFERENTIAL THRESHOLDS OF SLIDES 1-24

| | | Departure from pattern | | Vertical displacement | |
|---|---|---|---|---|---|
| Subjects | Slides | F | p | F | p |
| RDB | 1-12 | 1.60 | $>.01$ | 10.4 | $.01>p>.005$ |
| | 13-24 | 1.43 | $>.01$ | 8.5 | $.025>p>.01$ |
| LB | 1-12 | 2.90 | $>.01$ | 149.4 | $<.001$ |
| | 13-24 | 3.80 | $>.01$ | 41.7 | $<.001$ |

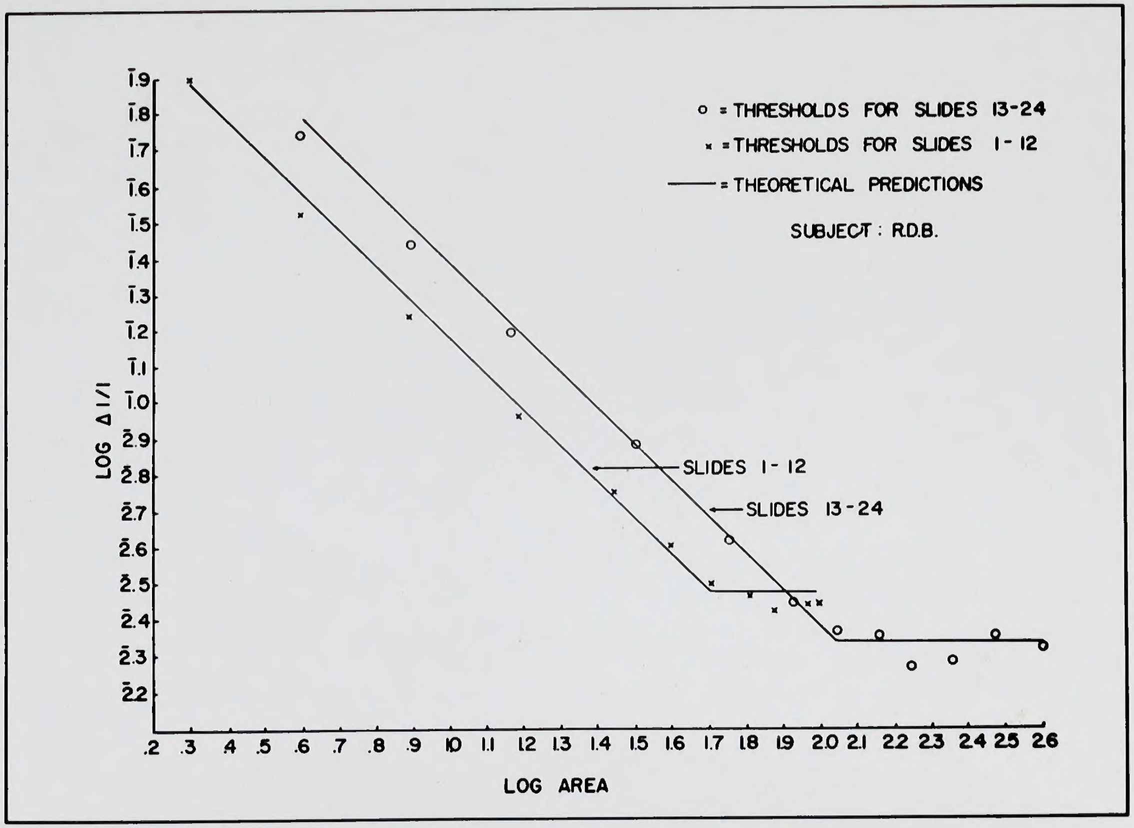


FIGURE VIII

FINAL DIFFERENTIAL THRESHOLDS (LOG $\Delta$I/I) AS A FUNCTION OF LOG AREA. THE SOLID LINES ARE PREDICTED FROM EQUATION (3a) SUBJECT RDB

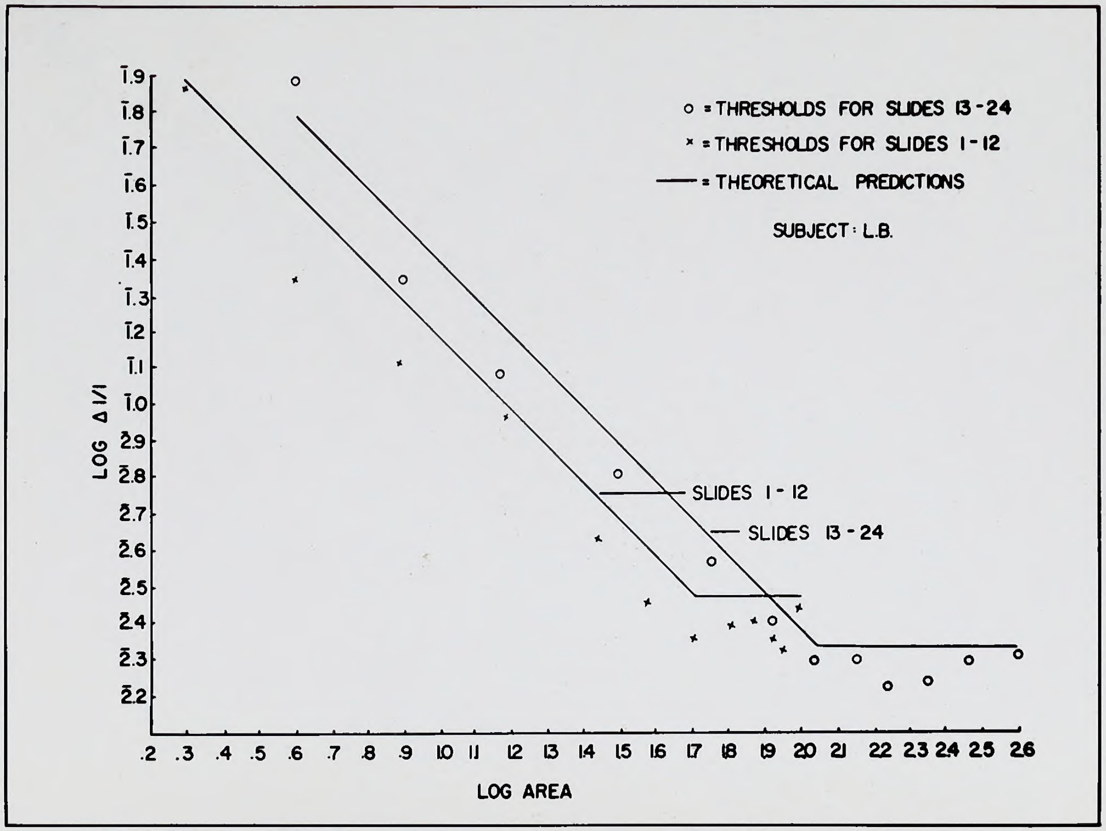


FIGURE VIIIA

FINAL DIFFERENTIAL THRESHOLDS (LOG $\Delta$I/I) AS A FUNCTION OF LOG AREA.
THE SOLID LINES ARE PREDICTED FROM EQUATION (3a)
SUBJECT LB

obtained for each of the four slides, A,B,C and D. The threshold values appear in Table VI. The differences between means were tested by an analysis of variance and a summary of the analysis appears in Table VII.

2. Effect of separation distance of the rectangles. Table VIII contains the five threshold values for the slides E,F,C and G. The summary of an analysis of variance for these slides appears in Table IX.

TABLE VI

DIFFERENTIAL THRESHOLDS (LOG $\Delta I/I$) OF SLIDES A, B, C AND D, DIFFERING IN SIZE OF PAIRS OF RECTANGLES
SUBJECT RDB

| | Slides | | | |
|---|---|---|---|---|
| Series | A | B | C | D |
| 1. | .4209 | .3713 | .3393 | .5089 |
| 2. | .4161 | .4241 | .4281 | .5137 |
| 3. | .4225 | .4897 | .4801 | .5441 |
| 4. | .3809 | .3553 | .4769 | .5649 |
| 5. | .4481 | .4281 | .5025 | .6129 |
| Means | .4177 | .4137 | .4454 | .5489 |

TABLE VII

VARIANCE TABLE FOR SLIDES A, B, C AND D, DIFFERING IN SIZE OF PAIRS OF RECTANGLES
SUBJECT RDB

| Source | Sum of Squares | df | Variance Estimate |
|---|---|---|---|
| Between | .0600 | 3 | .0200 |
| Within | .0378 | 16 | .00236 |
| Total | .0978 | 19 | |
| | F = | 8.48 | |
| | p | <.01 | |

TABLE VIII

DIFFERENTIAL THRESHOLDS (LOG $\Delta I/I$) OF SLIDES E, F, C AND G, DIFFERING IN SEPARATION DISTANCE OF A PAIR OF RECTANGLES SUBJECT RDB

| | Slides | | | |
|---|---|---|---|---|
| Series | E | F | C | G |
| 1. | .5313 | .3425 | .3393 | .3713 |
| 2. | .4977 | .4225 | .4281 | .4369 |
| 3. | .5840 | .5025 | .4801 | .4641 |
| 4. | .6001 | .4993 | .4769 | .5185 |
| 5. | .5793 | .4641 | .5025 | .3809 |
| Means | .5585 | .4462 | .4454 | .4343 |

TABLE IX

VARIANCE TABLE FOR SLIDES E, F, C AND G, DIFFERING IN SEPARTION DISTANCE OF A PAIR OF RECTANGLES SUBJECT RDB

| Source | Sum of Squares | df | Varinace Estimate |
|---|---|---|---|
| Between | .0514 | 3 | .0171 |
| Within | .0566 | 16 | .00354 |
| Total | .1080 | 19 | |

$F = 4.84$

$.05 > p > .01$

CHAPTER V

DISCUSSION

A. Experiment I

1. Predictions. Figures VI through VIIIA clearly indicate that slides 7-12 and 19-24 show an inverse relationship between area and differential threshold, $\Delta I/I$, and thus verify Prediction I. Likewise, Slides 1-6 and 13-18 have approximately the same threshold and thereby confirm Prediction II. Slides 1-12 and 13-24, differing in perimeter, have different thresholds which verifies Prediction III.

For each set of twelve rectangles, the area of the figures is continually increased. The results indicate that the threshold decreases initially and then remains constant. These results are clearly contrary to the predictions from equation (1) which postulated a simple reciprocal relation between area and intensity. They are also incompatible with the predictions from equation (2) of Graham which postulated a gradual reduction in the effects of area for larger figures. The thresholds of slides 13-18 are well below those of slides 1-6, although the differences between the dimensions of the two groups lies in areas greater than 3' from the center.

Finally, the theory of Lamar et al. was tested by determining whether or not their equation predicted the

data. The trend analysis indicated that the equation did predict the shape of the functional relationship between area and intensity. The value of c differed from the predicted value. C is a constant determining the overall level of the threshold and it is known that subjects will differ in sensitivity. The value of c obtained by Lamar et al. was a group average based on several subjects, and when individuals are tested, it is expected that they will deviate from this average.

2. Unpredicted findings. A more careful examination of the curves of Figures VIII and VIIIA indicates two interesting observations which may be of some significance, although they are not amenable to statistical test. The first concerns the level of the threshold for the two narrowest stimuli, 19.9' by .1' and 39.9' by .1'. For LB these two slides have excessively high thresholds compared to the trend of the other stimuli and in fact are responsible for a sizeable portion of the F-ratios of the trend analysis. For RDB these slides are more in keeping with the line of best fit although the threshold of one of them is a bit high. In the results of Lama r et al, their equation satisfactorally fit all the data except two of the very small targets of areas less than one square minute. The thresholds for these targets were too large and did not fit

their equation although this fact was not stressed in their study. It may be concluded that the results of the present study support the suggestion that the Lamar equation is inadequate to predict the thresholds of exceedingly small stimuli. Undoubtedly, limitations due to the size of cell structures and neural connections become an important variable at these small sizes.

The second observation concerns the point in the curve at which the threshold becomes constant as the area is increased. The predictions for the particular slides used were that beyond 51 and 111 square minutes the thresholds should be the same. It is clear from the data that there is no continual decrease in threshold as area is increased but the specific point at which the threshold becomes constant is not too apparent. It may be that the width of 3' is not critical but that some other value may be more adequate. The data for RDB, for example, show that slides 17' by 3' and 37' by 3' have slightly higher thresholds than the five other slides with which they should be equal. The same statement does not hold for the data of LB.

In conclusion, the data support the concept of useful area although it is not possible to confirm the particular value of width which is used to calculate the useful area.

B. Experiment II

1. Effect of the size of a pair of rectangles. Slides A, B, C and D were analyzed by an F test. The significant F-ratio which resulted from the analysis of variance was obviously attributable to the difference in threshold of slide D, (Table VII). Slides A, B and C had similar thresholds, although the total area of slide C was only half that of slide A. The similar thresholds of slides A, B and C (and F and G) verify Prediction IV. Slide D, on the other hand, presents somewhat of a problem. The slide consisted of two 20' by 3' rectangles separated by 14' and it was predicted to have the same threshold as slides A, B and C. As will be seen below, the high threshold of slide D can not be attributed to the large separation of the rectangles. It must therefore be attributable to a decrease in useful area. It seems natural to conclude that widths greater than 3' can be useful, a suggestion which was made earlier in the analysis of the data of the major experiment.

2. Effect of separation distance of the rectangles. The thresholds of slides E, F, C and G were obtained to determine what effect, if any, the distance separating two rectangles would have on their threshold. Analysis of variance resulted in significant differences between slides. The differences can again be attributed to one slide, E.

The other slides differing in separation distance between 5' and 20' have almost identical thresholds. The theory of Graham can not account for the equal thresholds of slides F, C and G. Furthermore, the deviant slide, E, has the smallest separation of the rectangles and has the highest threshold, a finding which is totally contrary to Graham's theory.

The separation of the rectangles in Slide E was 3', which again confirms the suggestion that the threshold will be altered in this region. It is interesting to note that the same relationships hold even though the 3' width in slide E was a strip of dark area rather than light area.

C. Relation of results to other studies.

From the foregoing discussion, it seems logical to conclude, as did Lamar, Hecht, Shlaer and Hendley, that the judgement of contrast is made across the boundary of a stimulus rather than over its area. The similarity between this conclusion and those investigators in the fields of physiology and optics is noteworthy.

Marshall and Talbot (20) have proposed a general theory of visual acuity based largely on their analysis of resolution of contours. In a simplified form, this is their analysis. 1) Because of diffraction of light by the pupil of the eye, each narrow line or edge of an object

produces a distribution of energy (the edge gradient), instead of a sharp line of energy difference on the retina. 2) The eye itself is subject to physiological nystagmus, i.e., slight involuntary eye movements of varying amplitudes and frequencies. The effects of diffraction and nystagmus are analyzed in the following way. A circular patch of light falling on the retina will lead to continuous stimulation of the receptors in the inner portion of the patch of light and to an absence of stimulation in the portions far from the patch. At the periphery of the patch, there will be alteration of stimulation as a result of the nystagmus; i.e., the cones at the edge of the patch will be turned "on and off" as a result of the eye movement. 3) Finally, Marshall and Talbot point out that the entire visual system is especially sensitive to changes in stimulation rather than to absolute amounts of stimulation.

From the above three facts, it can be seen that the neural response to a stimulus will be principally determined by the edge or contour of that stimulus. The response resulting from edge stimulation would therefore play a dominant role in the determination of the threshold.

Jones and Higgins (16) have extended the Marshall and Talbot analysis and have provided a theory which agrees with the data of Lamar et al. as well as with the results of the

present study. Using Adler and Fliegelman's (1) measures of the amount of physiological nystagmus, they computed theoretical values for summated temporal illuminance gradients of rectangular stimuli. They concluded that at the threshold of each rectangle these gradients are equal, and therefore can be used to predict the threshold. Jones and Higgins (13, 15) have also shown that edge gradient measures can be used to relate graininess and granularity of photographs and that the subjective quality of sharpness of a photograph can also best be understood in terms of an edge gradient effect.

Riggs and Ratliff (24, 22) have performed an interesting series of experiments which indicate some of the effects of physiological nystagmus on visibility. By attaching a small mirror to the cornea of a subject's eye, they produced a stimulus which moved in exactly the same way as the eye moved; thus the image of this stimulus remained stationary on the retina. By counteracting the normal physiological nystagmus of the eye in this way, they found that a straight line stimulus tended to disappear within a few seconds, and that the visibility of the line was also a function of its width.

The above brief review of the current work of other investigators indicates clearly that the results of Lamar,

Hecht, Shlaer and Hendley and the results of the present experiment are entirely consistent with contemporary views of the nature of the visual mechanism.

# CHAPTER VI

## SUMMARY AND CONCLUSIONS

The present experiment was designed to test a theory proposed by Lamar,Hecht, Shlaer and Hendley. The theory stated that the relationship between the size of a stimulus and the differential threshold, $\Delta I/I$, can be expressed by the following equation:

$$\Delta I/I = .13 \frac{P^{2/3}}{U.A.} \qquad (3a)$$

where: P = perimeter of the stimulus

U.A. = useful area of the stimulus, defined as the area within 1.5' from an edge.

Four predictions were made to test their theory. The predictions are as follows:

I. There will be an inverse relationship between the differential threshold, $\Delta I/I$, and area, for figures of less than a critical area and constant perimeter.

II. The differential threshold, $\Delta I/I$, will remain constant and independent of changes in area, for figures of more than a critical area and constant perimeter.

III. The differential threshold, $\Delta I/I$, will increase as the perimeter is increased, for figures of equal area.

IV. The differential threshold, $\Delta I/I$, can be predicted from equation (3a) for stimuli composed of two figures.

The first three predictions were tested by obtaining the differential thresholds, $\Delta I/I$, for a series of twenty-four rectangles, varying in area, useful area and perimeter. Within limits, these three predictions were confirmed.

The fourth prediction was tested by obtaining the differential threshold, $\Delta I/I$, for a series of seven stimuli composed of pairs of rectangles. Within limits, the fourth prediction was also confirmed.

It was further found that, 1) the Lamar theory may be inadequate to predict the differential threshold, $\Delta I/I$, for very small dimensions, 2) the value of useful area defined as the area within 1.5' from an edge may be slightly too small a measure and 3) within prescribed limits, the distance separating two rectangles was not found to have any effect on threshold.

In conclusion, the results of this experiment agree with the theory of Lamar, Hecht, Shlaer and Hendley, which states that the judgement of contrast is made across the

boundary of a stimulus rather than over its area. This conclusion was found to be consistent with current theories in related areas of visual experimentation.

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THE INFLUENCE OF SIZE AND SHAPE
ON VISUAL INTENSITY DISCRIMINATION

Abstract of a Dissertation

Submitted in partial fulfilment of the requirements

for the degree of Doctor of Philosophy

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Many experiments have been performed to determine the variables which affect the differential intensity threshold. These experiments have led to several theories which relate decreases in threshold to increases in size of the stimulus. The present study is an attempt to test these theories by determining the effect of size and shape on the differential threshold.

Most investigators state that threshold is some form of inverse function of the total area of the stimulus. Lamar, Hecht, Shlaer and Hendley, in contrast, state that the threshold is an inverse function of the "useful area", which is defined as the area within a specified distance from the edge of the stimulus. For a background intensity, I, of 17.5 footlamberts, the differential threshold, $\Delta I/I$, is given by the following equation:

$$\Delta I/I = .13 \frac{P^{2/3}}{U.A.}$$

where: P = perimeter of the stimulus
U.A. = useful area, the area within 1.5'
from an edge.

The present experiment tests the following predictions from the above equation by varying the area, the useful area and the perimeter of series of rectangles.

Prediction I. There will be an inverse relationship between the differential threshold, $\Delta I/I$, and area, for figures of lessthan a critical area and constant perimeter.

Prediction II. The differential threshold, $\Delta I/I$, will be constant and independent of changes in area, for figures of more than a critical area and constant perimeter.

Prediction III. The differential threshold, $\Delta I/I$, will increase as the perimeter is increased, for figures of constant area.

Prediction IV. The differential threshold, $\Delta I/I$, can be predicted from the equation of Lamar et al. for stimuli composed of two figures.

The apparatus was designed so that size, shape and intensity of stimuli could be varied while presented against a constant background intensity of 17.5 footlamberts. The image of an evenly illuminated $30^{\circ}$ background screen was reflected from a piece of plate glass. An increment in intensity, $\Delta I$, was transmitted through the plate glass and appeared to be superimposed on the background. The amount of $\Delta I$ was varied by moving a light source to and from a piece of opal glass which acted as the secondary source. The size and shape of $\Delta I$ was changed by prepared slides

which were placed in front of the opal glass.

The stimuli were made from razor blade edges which were arranged to permit the transmission of light in various sizes of rectangles. Slides 1-12 (perimeter of 40') varied from 10' by 10' to 19.9' by .1'. Slides 13-24 (perimeter of 80') varied from 20' by 20' to 39.9' by .1'. Slides B, C and D consisted of pairs of rectangles varying in size from 20' by 3' to 20' by 7' and in separation distance from 14' to 6'. The first slide, A, of this series, was a 20' by 20' square. Slides E, F, C and G, were pairs of 20' by 5' rectangles differing in separation from 3' to 20'.

The dimensions of slides 7-12 and 19-24 were constructed in order that the useful area varied in the same way as the total area. According to Prediction I, these slides should have different thresholds. The dimensions of slides 1-6 and 13-18 were constructed in order that the useful area remained constant while total area was varied. According to Prediction II, these slides should have equal thresholds. According to Prediction III, slides of comparable area from 1-12 and 13-24 should have different thresholds because of differences in perimeter. Slides A-G, though varying in total area and separation distance, were predicted to have approximately equal thresholds, because they varied in perimeter and in useful area at about the same rate.

Thresholds for each of slides 1-24 were obtained from each of two paid subjects using the up-and-down method. Two thresholds, each based on fifty responses were obtained for each slide. Thresholds for each of slides A-G were obtained from one of the subjects using the same method. Five thresholds each based on twenty-five responses were obtained for each slide.

Comparisons of the thresholds based on each series of fifty responses, for slides 1-24, indicated that the measurements were reliable. Rank-order correlations between repeated measures of slides which were expected to vary in threshold as a function of area were always equal to 1.00. Rank-order correlations of those slides which were expected to have equal thresholds were never significantly different from zero.

Predictions of the thresholds for slides 1-24 were made from the equation of Lamar et al. A trend analysis was then used to determine whether the equation predicted the data. The pattern of the data was correctly predicted by the equation but there was significant vertical displacement between the data and the predicted values. The vertical displacement refers to the value of the constant, .13, which determines the overall level of the threshold.

An analysis of variance was performed on the five repeated threshold measures of slides A, B, C and D. A significant F-ratio resulted which was attributable to the deviation of slide D. The other three slides had almost identical thresholds.

An analysis of variance was also performed on the five repeated threshold values of slides E, F, C and G. A significant F-ratio resulted which was also attributable to the effects of a single slide, E, because the other slides had almost identical thresholds.

The first three predictions were verified by the thresholds of slides 1-24. As predicted, slides 7-12 and 19-24, which varied in useful area, differed in thresholds; slides 1-6 and 13-18, which did not vary in useful area, had equal thresholds; slides of comparable areas from 1-12 and 13-24 differed in perimeter and had different thresholds. Furthermore, the equation as a whole was found to predict the data adequately. The fact that the constant differed probably reflects nothing more than the individual differences in thresholds of subjects. Although the general concept of useful area was substantiated by the data, the data were too variable to state precisely if the value of 1.5' from an edge is the correct amount. Perhaps a value slightly larger might have resulted in better predictions.

There was also some doubt about the adequacy of prediction for two of the narrowest rectangles. For one of the subjects, the thresholds for the narrowest rectangles were much larger than predicted. Similar findings were reported by Lamar et al. and the predictions may be inadequate for very small stimuli.

The predictions for slides composed of two figures were also verified, because slides A, B and C, and C, F and G had equal thresholds, indicating that there was no effect due to changes in total area or separation distance. However, slide D, which was composed of rectangles of 3' width, and slide E, which was composed of rectangles separated by 3', were both found to have higher thresholds than the other slides. This is probably due to a decrease in the amount of useful area which strengthens the earlier suggestion that a value larger than 1.5' from an edge may be a more satisfactory definition of useful area.

In conclusion, the results of this experiment substantiate the theory of Lamar, Hecht, Shlaer and Hendley, which states that the judgment of contrast is made across the boundary of a stimulus rather than over its area.

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The candidate was born in New York City on November 28, 1928, son of William and Ray Nachman. In June, 1948, he received his A.B. from the Washington Square College of New York University. In June, 1949, he received his A.M. in experimental psychology from Boston University, and was accepted as a candidate for the Ph.D. in experimental psychology. He was appointed as an Assistant in the Psychology Department during 1949-1950; as a Teaching Fellow during 1950-1951; as a Lecturer during 1951-1952; and as an Instructor in the Summer Sessions of 1951 and 1952. He also held half-time appointments as a Research Assistant at the Boston University Optical Research Laboratories during 1950-1951; as a Research Assistant at Wesleyan University in Middletown, Connecticut during 1951-1952; and as a Research Assistant at the Boston University Physical Research Laboratories during 1952-1953. In September, 1953, he was appointed as an Assistant Professor of Psychology at the University of Colorado.